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ENGINEERING IN THE PREMAFROST ENVIRONMENT

PRELIMINARY SITE INVESTIGATIONS

by

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INTRODUCTION

Exploratory site surveys may be thought of as the first step in a series of approximations in which construction requirements are closely co-ordinated with , or influenced by, climate and terrain conditions. Knowledge of climate, terrain features and logistics in the Canadian north is necessary before exploratory survey planning can commence. The principle responsibility of an exploratory survey is to evaluate the capabilities of the terrain to accommodate the intended construction, through a thorough appraisal of the distribution of permafrost-affected terrain in relation to the construction limits, and to obtain sufficient information in the field to determine the properties of the surface material. Most problems are caused by the thawing of the permafrost which may contain large quantities of ice; therefore, it is necessary to know the properties of the surface material under frozen and thawed conditions.

Airphoto interpretation can be usefully employed to stratigraphically delineate terrain units on the basis of permafrost distribution, soil type, vegetation, topography, drainage, etc. These terrain units can then be evaluated on the basis of known ground information as to their suitability to support the proposed land use. Field checking should be planned on the basis of the discriminant selection of points to be evaluated, taken from the aerial photographs.

Geophysical methods are usefully combined with the analysis of aerial photographs in determining the extent of permafrost.

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OBJECTIVES OF PRELIMINARY EXPLORATORY OBSERVATIONS

The aim of exploratory engineering site surveys is to assemble, in the most economical fashion, preliminary terrain information for an assessment of the site conditions which will control the design of the proposed structure and its related construction methods. Design and construction techniques employed in the temperate parts of our country must be modified to take into account the effects of a changing climate with increasing latitude. For example, consider the location of buildings in the Arctic. Buildings should be orientated taking into account prevailing wind and exposure. Living areas should be confined to the areas on the leeward side of the building to be protected from the prevailing winds (usually north or north-west).

The objectives of preliminary site exploration are controlled by many factors. Amongst these is the important consideration of the type of construction that is proposed. The design and construction of various land use activities can be subdivided into two separate categories: areas requiring corridor selection such as pipelines and roads and, secondly, areas confined to one specific geographic location. (See Figure 1)

Generally, any study required for exploratory survey purposes must begin with a thorough literature research. The following headings can be used as a minimum guideline for the type of information required for location surveys:

1) occurrence and distribution of permafrost;
2) geology (bedrock and surficial);
3) soil type;
4) climate;
5) vegetation;
6) logistics;
7) construction experience in locality.

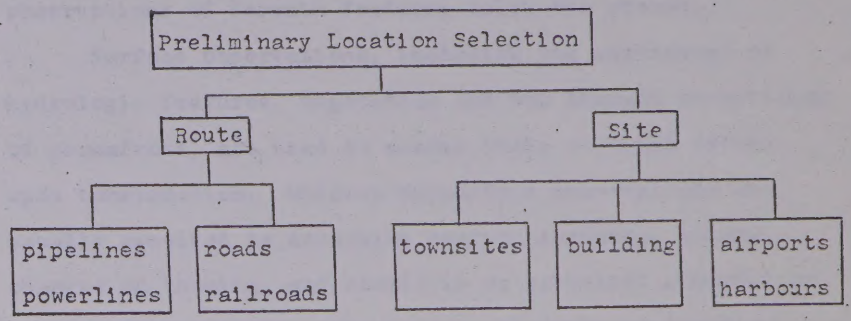

Figure 1

SITE OBSERVATIONS

Site observations depend upon the land use under consideration. The selection of a corridor for a road location requires the assessment of parameters which may vary with increasing latitude; whereas the selection of a townsite, unless it is already determined by other requirements, is dependent upon selecting a site which combines the best of the required conditions.

Independent of location, site investigations consist of three phases which must be completed to determine the best site or route. These phases are: (1) preliminary office studies and planning; (2) field investigations; and (3) laboratory, model studies and office work prior to the preparation of reports. It is generally accepted that a minimum of one year's evaluation of a particular site is required to provide adequate site investigation in permafrost areas.

The preliminary office studies and planning, the first phase of site observation, entails assembling pertinent information several months prior to the field season. The beginning of the field season depends upon latitude but is approximately late March or early April. Some assessment of design and construction requirements can be made at this time. The analysis of aerial photographs provides the most valuable aid for preliminary planning. The aerial photograph, which serves as a map, can be used to interpret directly or infer a number of terrain characteristics, which greatly control site or route location. Table 1 presents, in matrix form, parameters for land use site selection with their relative importance to route and site locations.

The requirements of exploratory observations are a function of the geographical position, extent of the route or site, and construction experience pertaining to the area (established or unknown area). The location engineer is responsible for investigations which may be divided into two broad categories: surface observations of terrain features above and along the ground surface and secondly, subsurface observations of terrain features below the ground.

Surface observations, including the assessment of hydrologic features, vegetation and the thermal sensitivity of permafrost, are used to assess their combined effect upon construction; whereas subsurface observations are usually assessed to determine bearing capacity, volume changes on thawing, and stability as potential controls on construction methods. The terrain elements of landform, including patterned ground, drainage and vegetation are utilized in terrain interpretation of surface observations. The identification of various landforms such as pingos, thermokarst lakes, "drunken forests", ground subsidence caused by thawing of large buried ice masses, solifluction lobes or terraces, frost mounds, hummocks, mud boils, etc., all can be used in the determination of the most suitable site. Particular attention should be given to locating the

Table 1 - Airphoto Interpretation and Location Engineering

	Interpretability	Terrain Characteristics (as interpreted from panchromatic aerial photographs)	Land Use Selection					
			Route		Site			
			Pipelines Powerlines	Roads Railroads	Townsites	Buildings	Harbours	Airports
1	D	Engineering Soil Type	1	1	1	1	2	1
2	I	Depth of Overburden	1	1	1	1	2	1
3	D	Topography	1	1	1	1	1	1
4	D	Surface Drainage	1	1	1	1	1	1
5	I	Water Table Elevation	1	1	1	1	1	1
6	I	Subsurface Drainage	1	1	1	1	1	1
7	D	Erosion (wind, water, gravity)	1	1	1	1	1	1
8	I	Water Supply (and type)	3	3	1	1	1	3
9	D	Sewage Disposal	3	3	1	1	2	2
10	D	Access	1	1	1	1	1	1
11	I	Wind Direction	2	1	1	1	1	1
12	D	Location relative to other land use	1	1	1	1	1	1
13	I	Permafrost Distribution	1	1	1	1	1	1
14	I	Terrain Trafficability	2	1	1	1	2	3
15	I	Soil Moisture	1	1	1	1	2	1
16	D	Granular Material	1	1	1	1	1	1
17	I	Bearing Capacity	2	1	1	1	1	1
18	D	Vegetative Cover	2	2	2	2	3	2
19	D	Shoreline Evaluation	1-3	1-3	1-3	1-3	1-3	1-3
20	P	Pollution	1	2	1	2	1	2

Legend for Interpretability

D - may be interpreted directly from airphotos
I - may be inferred from interpreted information
P - possible to interpret from airphotos

Legend for Terrain Characteristics

1 - must always be closely investigated
2 - should be investigated on preliminary basis
3 - not of concern in most cases

natural drainage paths or forms and how these may change during the various seasons. In potentially troublesome terrain, drainage observations are usually extended so that alternate drainage remedies may be considered. The descriptive system for surface vegetative cover is based on one presently in use for muskeg. ("Guide to a Field Description of Muskeg") This system recognizes nine basic vegetation cover classes by the qualities of woodiness, height, texture and growth habit. Many of the individual patterned ground types are not individually discernible on aerial photographs but collectively contribute to a distinct terrain pattern.

Field descriptions of sites selected for field checking from the aerial photographs are concerned with size and elevation of landforms, spacing type, and diameter of the characteristic vegetation, local drainage pattern, subsurface materials and changes in the seasonal depth of thaw. Subsurface explorations are concerned with a description of materials and conditions below the ground surface. Three conditions of the subsurface material are recognized -- thawed, perennially frozen and seasonally frozen. The distinction between seasonally frozen and perennially frozen soil is usually difficult to make on the basis of field inspection. The seasonal depth of thaw, as well as its variability, have long been recognized in permafrost areas. There is still a tendency for engineers to regard it as a definite thickness per locality. This difficulty is probably caused by a misunderstanding of the terms active layer and seasonal depth

TABLE 2

Unified Soil Classification System

Major Divisions			Group Symbols	Typical Names
Coarse-grained Soils	Gravels	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.
	More than half of coarse fraction is larger than No. 4 sieve size		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.
More than half of material is larger than No. 200 sieve size.		Gravels with fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.
			GC	Clayey gravels, gravel-sand-clay mixture.
	Sands	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines
The No. 200 sieve size is about the smallest particle visible to the naked eye.	More than half of coarse fraction is smaller than No. 4 sieve size.		SP	Poorly graded sands or gravelly sands, little or no fines.
	(For visual classification, the ¼-in. size may be used as equivalent to the No. 4 sieve size).	Sands with fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.
			SC	Clayey sands, sand-clay mixtures.

TABLE 2 - Cont'd
Unified Soil Classification System

Major Divisions		Group Symbols	Typical Names
Fine-grained Soils	Silts and Clays	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine, sands or clayey silts with slight plasticity.
More than half of material is smaller than No. 200 sieve size.	Liquid limit is less than 50	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
		OL	Organic silts and organic silty clays of low plasticity.
The No. 200 sieve size is about the smallest particle visible to the naked eye.	Silts and Clays	MH	Inorganic silts, micaceous or diatomaceous fine, sandy or silty soils, elastic silts.
	Liquid limit is greater than 50	CH	Inorganic clays of high plasticity, fat clays.
		OH	Organic clays of medium to high plasticity, organic silts.
	Highly Organic Soils	Pt	Peat and other highly organic soils.

of thaw. The active layer is the zone where seasonal freezing and thawing occurs; whereas the seasonal depth of thaw is the thawed zone for an environment in a locality at some particular time during the thawing season and only at the time of its maximum depth can it correspond to the active layer. The depth of the seasonal thaw should be recorded along with the date, because the seasonally thawed layer does not correspond to the active layer until late October, and at all other times it is less dependent on the date of observation. Changes in the depth of thaw are usually the result of changes in surface conditions such as vegetation, relief and drainage. It is useful to make many random observations at a site and then to record not only the average, but also the maximum and minimum depths of thaw.

The subsurface materials should be described in two parts: the soil, including organic, and the ice portion. The Unified Soil Classification System should be used to describe the soil. (See Table II, Unified Soil Classification). In this classification system, the soil is grouped into three major divisions depending on its grain size and organic content. Coarse grained soils may be described briefly as those soils composed of particles visible by eye. Fine grained soils are composed of particles that are not visible to the eye. Descriptions of fine grained soils should make reference to the following characteristics: consistency, plasticity, structure, colour and odor. Organic soils are placed in a separate group because of their appreciable organic matter content. Partly organic soils which are composed mainly of mineral type, are described as the predominant soil modified by the word organic (for example, organic silts). Soils which are mostly organic may be described as peat which has further subdivisions based on organic particle characteristics.

The ice portion descriptions are based on the physical form of the ice in frozen soils and are intended to aid in the description of ice and soil, rather than to classify according to properties, or performance of frozen soils. The ice portion of frozen soils is divided into three major groups in which the ice is:

(a) <u>not visible</u> by eye

(b) <u>visible</u> by eye with individual ice layers <u>less</u> than one (1) inch thick.

(c) <u>visible</u> by eye with individual ice layer <u>greater</u> than one (1) inch thick.

(Pihlainen, 1963)

Frozen soils with ice segregation not visible by eye are usually stable on thawing. When ice segregation is visible, thawing usually produces an unstable condition. The thawing is accentuated if the water and mineral soil flows away because of a gradient. Under this condition, the necessary formation of an active layer for the equilibrium condition, will not occur and the erosion will continue.

The methods of obtaining subsurface information may

be grouped into three possible methods:

(1) direct methods, which involve the actual sampling and inspection of subsurface materials;

(2) indirect methods, which require the inference of subsurface material from terrain characteristics; and,

(3) semi-direct methods which involve the correlation of limited direct methods with some easily measured properties and then the extrapolation of such findings to unknown areas.

The direct methods of subsurface observations are most commonly utilized in the North because they are adaptable to most site surveys and variable terrain conditions. The direct methods include observations of natural soil exposure, hand borings and probes, test pits and drilling. Observations of natural soil exposures, hand borings and probes are restricted by frozen ground to shallow depths. Terrestrial photographs are a useful record of conditions found in the field and can be used in combination with aerial photographs to provide a complete record of a site.

Test pits provide more detailed information about subsurface conditions but require more effort and capital expenditure. They are however not restricted by frozen ground or the type of subsurface material and may be utilized in all types of site surveys to a depth and extent dictated by project requirements. The drilling methods of subsurface exploration require the most elaborate equipment and specialized personnel.

The indirect methods of subsurface observations are based on an inference of subsurface materials and conditions from visible terrain characteristics. Depending on knowledge from past experience, the exploration engineer is able to predict subsurface materials after an analysis of terrain elements such as landform, drainage and vegetation.

Two types of semi-direct methods involve the use of probing or sounding and geophysical methods. Subsurface probing or sounding consists of forcing or driving a rod, pipe or rail into the ground and observing the penetration resistance, usually in blows per foot. Geophysical methods of subsurface exploration consist of identifying changes in the character of subsurface materials by measuring changes in certain physical properties of the earth, recorded at or near its surface. The major geophysical methods involve measurement of surface irregularities in the gravitational, magnetic and electrical fields of the earth and measurement of changes in electrical resistance and rate of propagation of elastic waves in the earth. They are classed as gravitational, magnetic, electrical and seismic methods. The application of geophysical methods to mapping the areal distribution of permafrost have not proven too reliable. The two principle objectives of sampling are the identification and classification of the soils and, secondly, an evaluation of the ice content.

THE REQUIREMENTS OF LOCATION SURVEYS

As mentioned previously, the extent of site exploration observations is controlled by many factors. Amongst these is the important consideration of the type of construction that is proposed. In the discontinuous and continuous permafrost zones, various types of construction work, (transportation routes or local site selection for a building), require different applications of construction design.

The requirements for site selection will be discussed under two broad categories: route selection and site selection.

(a) ROUTE SELECTION

The selection of a route for roads and railroads compared to pipelines and powerlines differs only in the information required for foundation design. The continuous support required for roads and railroads necessitates a more thorough understanding of the terrain. The design of roads and railroads is based on the preservation of permafrost. Accordingly, cut sections are avoided and road location may be governed by fill material sources. Although the major design consideration of roads is settlements, the implications of road drainage are almost as great. Subsurface explorations should also be located at potential material locations, remembering that peat and organic fill are used as a road construction material as well as granular fill. The depth of exploration will depend, to a large extent, on the character and sequence of the subsurface strata. As a guide, the minimum depth of exploration should be 10 feet in areas of discontinuous permafrost and 5 feet in areas of continuous permafrost. If no attention is paid to drainage, the construction of a road in a permafrost area may act as a dam impounding water from natural drainage. Three main consequences of impounding water are:

(1) an increased thawing of permafrost;

(2) a supply of source water for frost action; and

(3) the occurrence of "icings".

For winter maintenance, such as keeping roads clear of snow drifts, there is much advantage in locating roads in the direction of prevailing winds and minimizing abrupt alignment changes.

Assuming that a pipeline will require support at specific locations similar to the towers for transmission lines, the extensive site investigations concentrate on local areas suitable for the best support.

The following notes on "Criteria for Road Location in Permafrost Regions" are quoted directly from a paper presented by J. Y. C. Quong at the "Seminar on the Active Layer and Related Problems" sponsored by the National Research Council, 4 - 5 May, 1971.

Criteria for Road Location in Permafrost Regions

Normal Criteria

- shortest route;
- standard alignment and grades;
- reasonable economical design;
- traffic volume, traffic safety, etc.

Permafrost Areas

- Favorable foundation and drainage conditions govern rather than directness of route;
- avoid areas of degrading permafrost table;
- avoid areas with ground heaving;
- avoid wet hill sides and slopes to preclude slope failures, slides and icing;
- keep above known icing elevations in rivers and ice jamming that may be marginal to or cross the road;
- locate road parallel to rather than across ground water movement;
- locate on south slopes of hills and mountain ranges to take advantage of solar heat and ground likely permafrost-free, early thaw and late freezeup, less icing, etc.
- avoid locating too close to river banks where permafrost table may dip at steep slope toward river;
- avoid areas of polygoning, springs, solifluction.

Snow Consideration

- Avoid cuts which will induce snow drifting and may cause ground icing from seepage;
- keep grade above surrounding ground to reduce snow accumulation.

Design Considerations

- Do not attempt to balance cut and fill;
- use flattest vertical and horizontal curves feasible.

Construction Considerations

- Take advantage of thawed riverbeds for materials as necessary;
- rugged relief indicate more well defined drainage pattern and non frost-active soils;
- flood plains are good sources for gravel; braided stream indicate stratified gravel and sand.

Bridging Considerations

- Check stream icing tendency and build-up level;
- check breakup water level and ice jamming tendency;
- check channel shifting possibility especially in young braided streams and from erodible banks;
- check flash flooding tendency from ice damming upstream;
- check driftwood size and quantity;
- choose crossing confined by geographic feature; use level crossing if possible;
- locate bridge crossing ahead of road if possible as controlling element.

Ground Reconnaisance Check List for Road Construction in Permafrost

- Note type and extent of clearing required;

- study surface and ground water characteristics thoroughly; note source, quantity, direction of movement, rate of flow;
- note snow depth and probably runoff, evidence of icing;
- probe to determine depth of permafrost table;
- note evidence of detrimental frost action;
- note characteristics of active layer and ground covering (type, depth);
- note areas with highly frost-susceptible conditions for detail investigation.

Transportation Considerations

- Note existing trails, airstrip, water transportation facilities (lakes, rivers, best access route, etc.).

Soils Investigation

- Test holes 10 feet minimum.
- Make supplementary subsurface investigation for conditions such as :
  - Changes in slope exposure,
  - breaks in slopes,
  - areas to be excavated,
  - areas with changes in vegetation, soil, etc.,
  - areas to be covered with a very high fill,
  - swamps and depressions,
  - areas subject to sliding,
  - sites of springs and field icing for water table,
  - potential borrow sites,
  - occurrence of rock under overburden, etc.

Construction Considerations

- Determine timing for mobilization and evacuation of construction crews;
- Locate camp site, water supply, waste disposal areas, etc.;
- Determine temperatures, precipitation, humidity, wind direction and velocity, frequency of storms;
- Note shortest access to borrow pits, drainage requirements.

Some Design Criteria

Drainage:

- In general, avoid excavating ditches if possible, and avoid ponding of water at the toe of fill;
- provide an adequate number of cross drains and discharge into natural drainage channels away from the road;
- construct ditches to intercept sidehill drainage but locate as far away from tow of fill as possible; use deep narrow ditches;
- provide ditch checks to preclude erosion.

Road Cross Section

- Avoid cuts;
- provide 3 to 4 foot minimum fill depth; avoid very high embankment;
- use at least 2:1 slopes; flatten to 5:1 for snow drift control;

- allow for softening of ground at toe due to compression of organic cover and consequent water ponding;
- keep earthwork to minimum but consistent with geometric requirements;
- provide for adequate surface drainage on road; use 4% minimum.

) SITE SELECTION

Site selection, in contrast to route selection, is based on an appraisal of the location on the basis of its ability to best satisfy the needs of the proposed design. Location surveys in the discontinuous zone try to evaluate the permafrost distribution and avoid detrimentally frozen ground for townsite, buildings or airports.

Townsites are selected on the basis of a number of elements which interact to provide the best site. The following list of elements has been found useful, as a basis for a first appraisal of areas to be used as townsites:

- access,
- size,
- location,
- potential for future development,
- subsurface materials,
- water supply,
- sewage disposal,
- airstrip location,
- overland erosion, and
- availability of local construction materials including timber and gravel.

The evaluation of sites is based on the best combination of all those factors previously listed and when other conditions are equal, preference is given to sites that are:

(1) Flat and dry;

(2) Not subject to flooding;

(3) Free of the features which indicate permafrost such as icings, frost-mounds, cave-ins, and swamps;

(4) Distant from mountain slopes (areas near the foot of mountains are susceptible to icings, frost-mounds and ground-ice because of ground-water under hydrostatic pressure.

(Muller, 1947)

At times there is much advantage to include the direction of prevailing winds in townsite layout. A minimum of building area should be exposed to the prevailing winds, as mentioned in the introduction, and all major entrances should be located on the windward side to be free from drifting snow. In established communities the direction of prevailing local winds are readily available; whereas, in unsettled areas, some indication may be obtained from snow drifts and in some areas, vegetation.

The factor which controls building design in the North is the state of the underlying ground. The principle problem is to obtain and maintain adequate foundation

support. The National Research Council of Canada has prepared a Building Code for the North, 1968, to be used for design in norhtern parts of this country. If field tests reveal a suitable surface condition, small buildings with a minimum of structural requirements may be supported directly by gravel pads, mudsills, timber pads or concrete pads placed directly on the ground surface. The choice of insulation used is a function of the availability of construction materials. However, if the building is a larger, more permanent structure the loads may be transferred to the soil by means of piles. With all foundations, built in the permafrost zone, it is necessary to minimize the transfer of heat from the superstructure to the ground.

The present technique of building on pile foundations allows for a ventilated foundation space which has a minimum clear height of approximately 2 feet, and will provide for relatively unobstructed air movement beneath the building.

The avoidance of heat transfer to the soil and the subsequent degradation of the permafrost is achieved by the methods mentioned. Gravel pads and piles are a "passive method" of construction used to prevent permafrost problems; whereas, the extremely costly "active method" of permafrost excavation is seldom used.

The design factors influencing the site exploration for air fields is dependent upon the geographical location of the site. In areas of continuous permafrost, the design of air fields is based on the preservation of the permafrost, if the soil at the proposed location does not seem to indicate suitable foundation material in the thawed state. Although a major design consideration of air strips is settlement caused by the degradation of permafrost, the physical requirements of an air field are of equal importance.

Air fields for small privately owned planes in small communities, not on present or proposed scheduled air carrier systems, may require a runway length up to 3,500 feet and a width of 100 feet. Larger communities located on present or proposed feeder lines, may require a runway length up to 6,000 feet and runway width of 150 feet. The slope of a straight line joining the centre points of the extremeties of a runway should not exceed 1%. The longitudinal slope should not exceed 1.5% along any portion of the runway. The transverse slope of a runway should be such as to prevent the accumulation of water on the surface. Details of the physical characteristics and the basis for evaluation of potential hazards may be found in the International Standards and Recommended Practices of the International Civil Aviation Organization titled "Aerodromes Annex 14 to the Convention of International Civil Aviation", 3rd edition, September 1958.

After an airfield is chosen from the many active considerations, subsurface explorations are carried out at 100 or 200 feet intervals along the centre line.

SUMMARY

The preliminary objectives of exploratory location selection are determined by the type of land use required, be it a transportation route or a local site for a town, building or airport. Airphoto interpretation is ideally suited to route or site selection data acquisition because of the vastness of Canada's North. An extensive survey of a number of selected corridors or townsites can be carried out very economically through the use of aerial photographs.

Preliminary field checking should be combined with the aerial photographic analysis of the optimum location. The requirements of any location vary from the discontinuous to the continuous zone. Design and construction procedures should be modified to consider the unique problems presented by permafrost affected terrain. Many of the problems introduced to the terrain sensitive region could have been avoided if southern techniques had been modified before their direct application in this little known environment.

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